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Pedersen

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(54) **METHOD AND APPARATUS FOR COIL-LESS MAGNETOELECTRIC MAGNETIC FLUX SWITCHING FOR PERMANENT MAGNETS**

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H02K 21/26 (2006.01)
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H02K 41/03 (2006.01)
H02K 99/00 (2014.01)
H01F 3/10 (2006.01)
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(52) **U.S. Cl.**

CPC **H02K 19/02** (2013.01); **H02K 19/10** (2013.01); **H02K 21/12** (2013.01); **H02K 21/26** (2013.01); **H02K 21/44** (2013.01); **H02K 41/03** (2013.01); **H02K 57/006** (2013.01); **H01F 3/10** (2013.01); **H01F 7/0205** (2013.01); **H01F 2003/103** (2013.01)

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USPC **336/155-165; 335/296-306; 310/321, 310/323.01**

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,806,858 A 2/1989 Elbicki
6,246,561 B1 6/2001 Flynn

(Continued)

FOREIGN PATENT DOCUMENTS

JP 62117757 A * 5/1987

OTHER PUBLICATIONS

Ryu et al., "Magnetoelectric Properties in Piezoelectric and Magnetostrictive Laminate Composites", Jpn. J. Appl. Phys., 40, 2001, 4948-4951.*

(Continued)

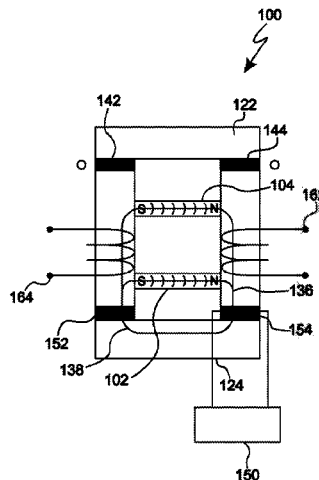
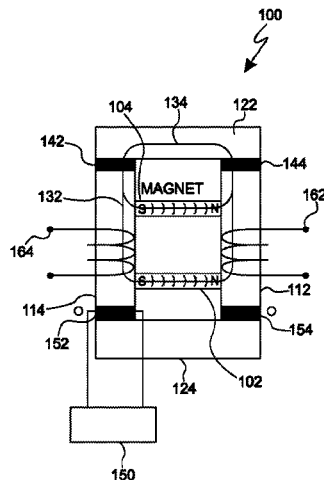
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(57) **ABSTRACT**

Methods and apparatus that employ a coil-less magnetoelectric flux switch arrangement to repeatedly switch magnetic flux from at least one permanent magnet for the purposes of generating motive force and/or electrical energy.

20 Claims, 7 Drawing Sheets



(56)

References Cited

U.S. PATENT DOCUMENTS

6,342,746 B1 * 1/2002 Flynn 310/181
6,835,463 B2 12/2004 Srinivasan

OTHER PUBLICATIONS

Inverse magnetostrictive effect, Wikipedia, no date.*
Magnetic susceptibility, Wikipedia, no date.*

Chang, et al., "Magneto-band of the Stacked Nanographite Ribbons", Mar. 2003, Publisher: American Physical Society, Annual APS March Meeting 2003, Mar. 3-7, 2003 abstract #01.034.
Filippov, et al "Magnetolectric Effects at Piezoresonance in Ferromagnetic-Ferroelectric Layered Composites", Mar. 2003, Publisher: American Physical Society, Annual APS March Meeting 2003, Mar. 3-7, 2003, , abstract #C1.018.
Ryu, et al., "Magnetolectric Effect in Composites of Magnetorestrictive and Piezoelectric Materials", Journal of Electroceramis, Aug. 2002, pp. 107-119, vol. 8, No. 2.

* cited by examiner

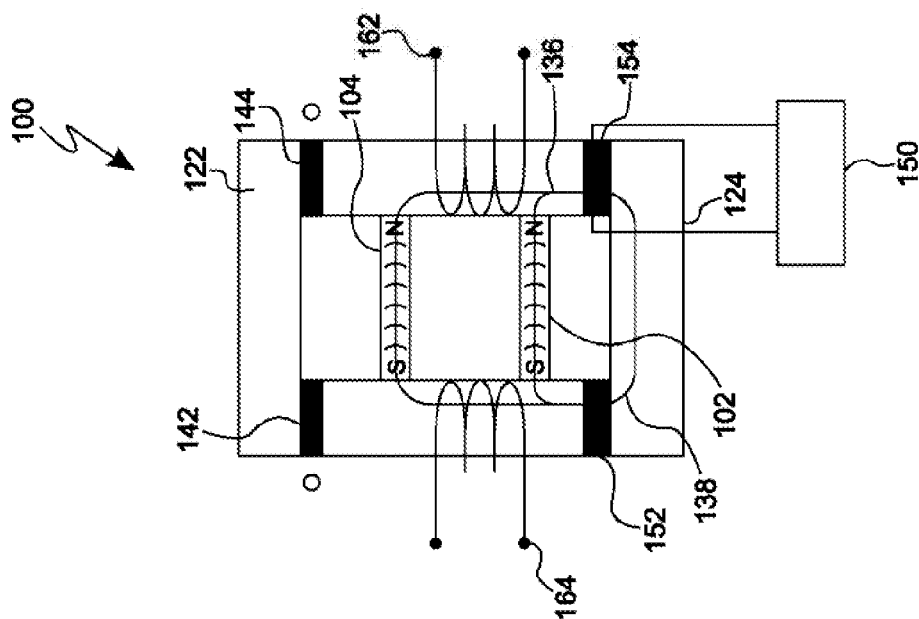


FIG. 1

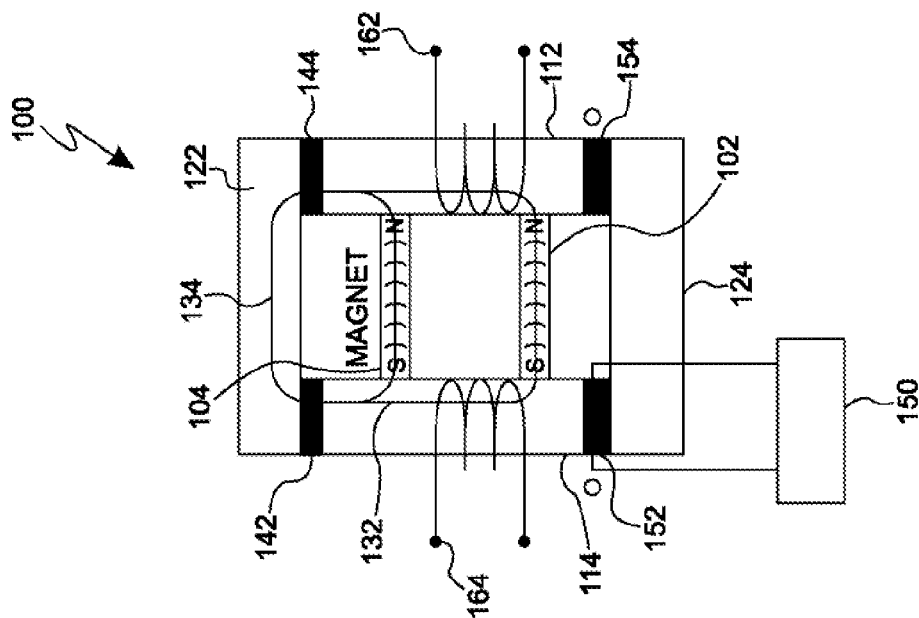


FIG. 2

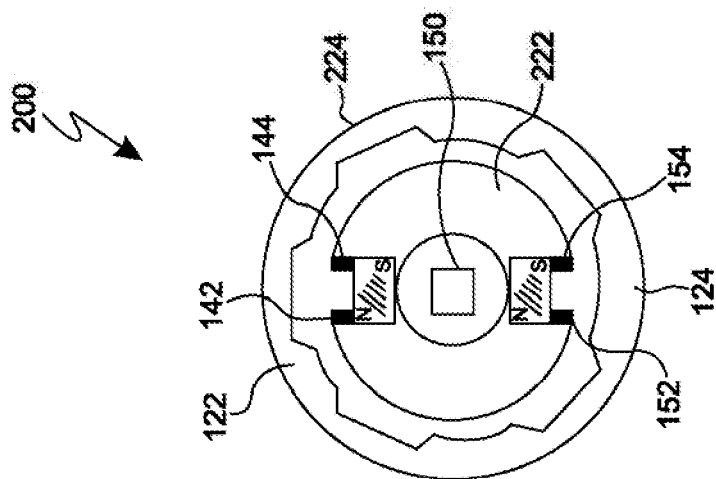


FIG. 3

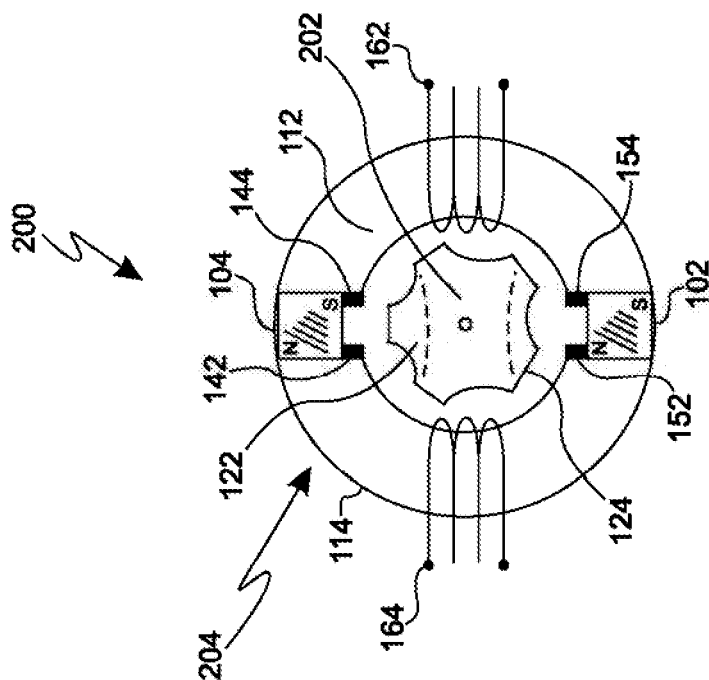


FIG. 4

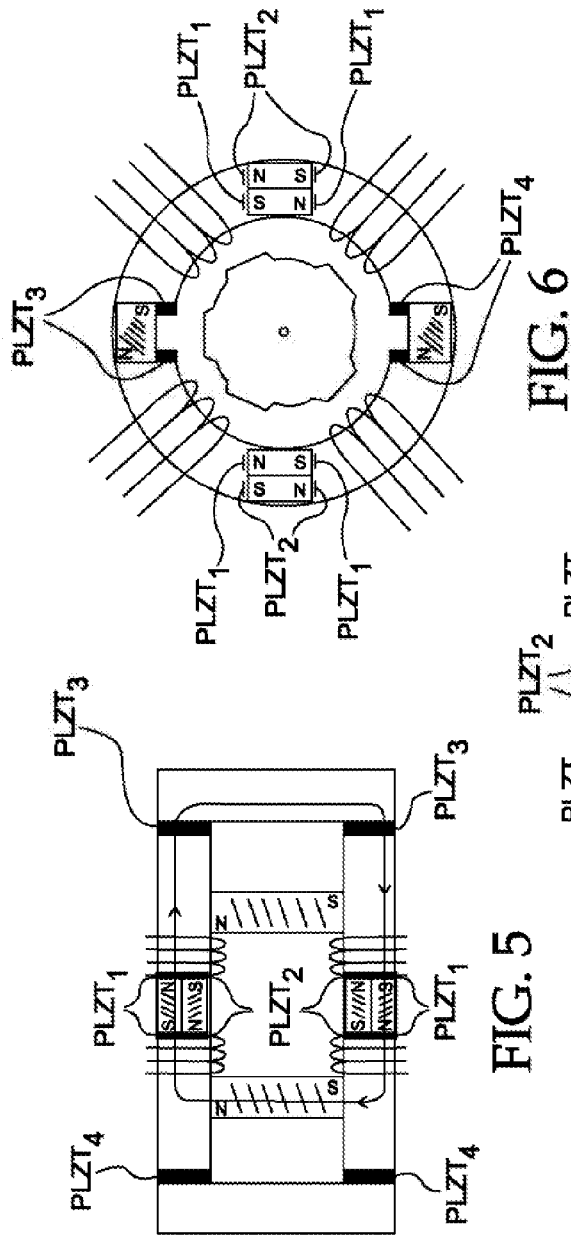


FIG. 5

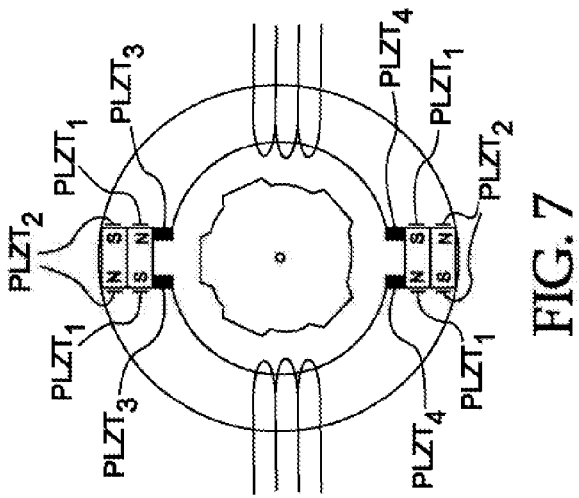


FIG. 7

PLZT₁ = 1
 PLZT₂ = 0
 PLZT₃ = 1
 PLZT₄ = 0

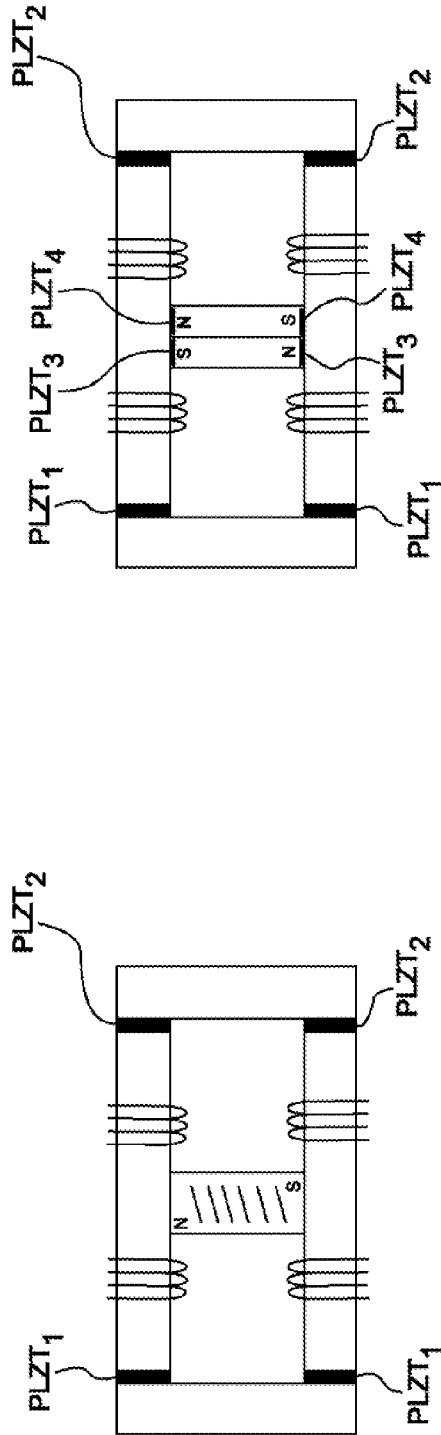


FIG. 9

FIG. 8

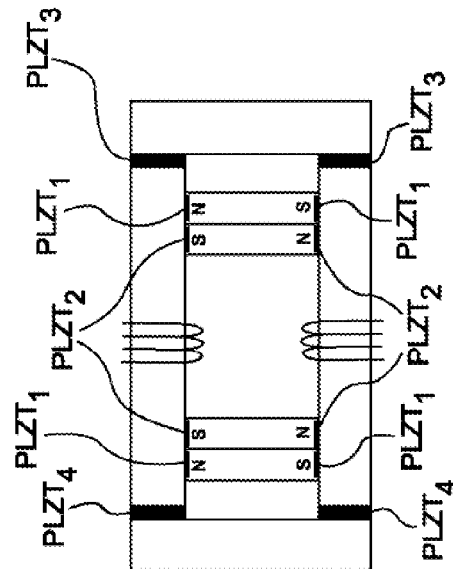


FIG. 10

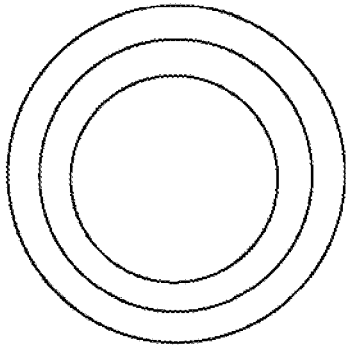


FIG. 11

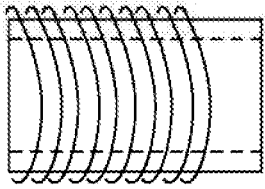


FIG. 12

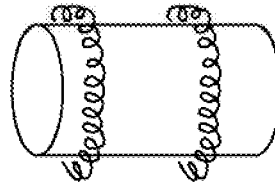


FIG. 14

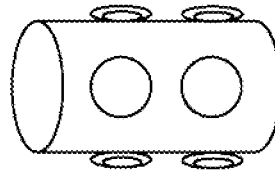


FIG. 13

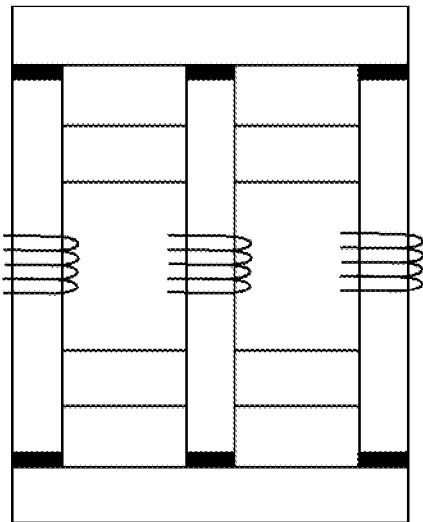


FIG. 15

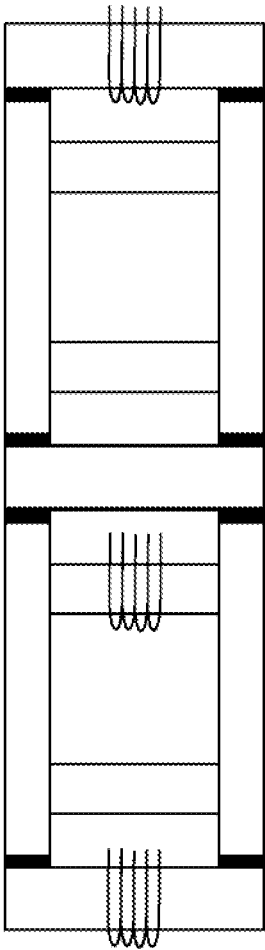


FIG. 16

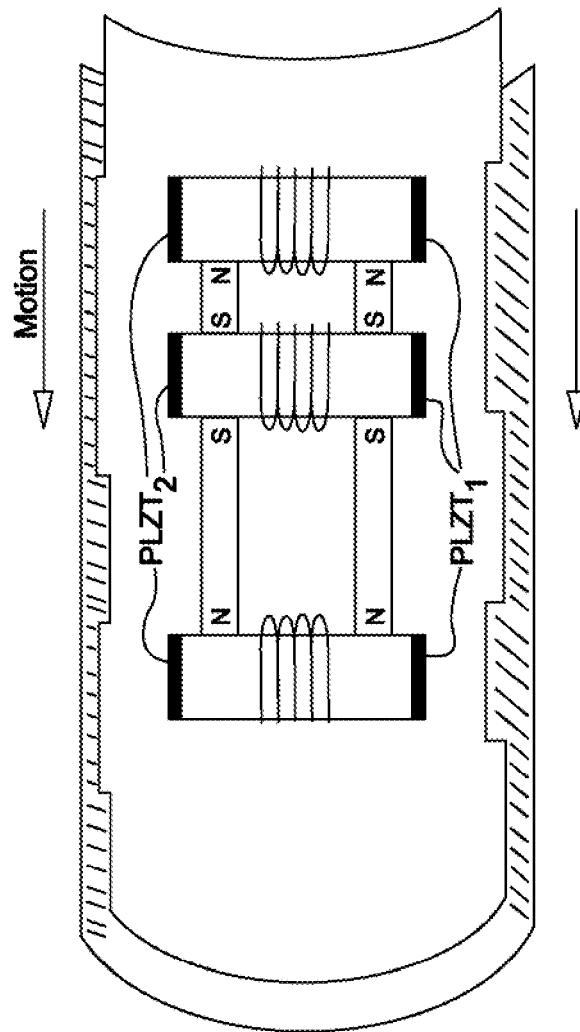


FIG. 17

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METHOD AND APPARATUS FOR COIL-LESS MAGNETOELECTRIC MAGNETIC FLUX SWITCHING FOR PERMANENT MAGNETS

This application is a continuation of application Ser. No. 12/719,845 filed Mar. 8, 2010, now abandoned, which is a continuation of application Ser. No. 11/950,155, filed on Dec. 4, 2007, now abandoned, the entire respective disclosures of which are hereby incorporated by reference herein. This '155 application is a continuation of application Ser. No. 11/279,162, filed Apr. 10, 2006, now abandoned, which is a continuation of application Ser. No. 11/229,079, filed Sep. 16, 2005, now U.S. Pat. No. 7,030,724, issued Apr. 18, 2006, which is a continuation of application Ser. No. 10/862,776, filed Jun. 7, 2004, now U.S. Pat. No. 6,946,938 issued Sep. 20, 2005, all of which are also herein incorporated by reference.

FIELD OF THE INVENTION

The present invention relates generally to magnetic fields from permanent magnets and the control of such magnetic fields for use in motors, generators and the like. More particularly, the present invention relates to methods and apparatus that employ a coil-less magnetoelectric (ME) magnetic flux switching construct to repeatedly switch magnetic flux from at least one permanent magnet for the purposes of generating motive force and/or electrical energy.

BACKGROUND OF THE INVENTION

The basic electro-mechanical processes involved in motors and generators are well-known. Mechanical power is produced (in the case of a motor) or electrical energy is generated (in the case of a generator) by the interaction of the electro-magnetic forces between the rotor and stator. While almost all conventional motors utilize electromagnetic forces produced by running current through a series of windings in the form of coils of wire to generate the electro-magnetic field that turns the rotor, the design of motors powered by magnetic fields from permanent magnets date back to as early as the 1840's. For numerous reasons, such permanent magnet powered motors have not been practical or competitive when compared to conventional electrical motors powered by electro-magnetic fields. For general background information on permanent magnets and permanent magnet motor design, reference is made to Moskowitz, Permanent Magnet Design and Application Handbook (1976), Hanselman, Brushless Permanent Magnet Motor Design (2003), and Gieras et al., Permanent Mamet Motor Technology Revised (2003).

Recently a permanent magnet powered motor construct has been proposed that overcomes many of the challenges long associated with permanent magnet motors. U.S. Pat. Nos. 6,246,561 and 6,342,746 issued to Flynn describe methods for controlling the path of magnetic flux from a permanent magnet and devices incorporating the same. In these patents, a permanent magnet device includes a permanent magnet having north and south pole faces with a first pole piece positioned adjacent one pole face thereof and a second pole piece positioned adjacent the other pole face thereof so as to create at least two potential magnetic flux paths. A first control coil is positioned along one flux path and a second control coil is positioned along the other flux path, each coil being connected to a control circuit for controlling the energization thereof. The control coils may be energized in a variety of ways to achieved desirable

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motive and static devices, including linear reciprocating devices, linear motion devices, rotary motion devices and power conversion.

It has long been known that certain materials commonly referred to as liquid crystals can be oriented by a magnetic field. As early as 1894, Curie stated that it would be possible for an asymmetric molecular body to polarize in one direction under the influence of a magnetic field. The practical application of this effect is most commonly seen in magnetically ordered crystals even in conditions of symmetry of the molecules of the crystal. U.S. Pat. No. 4,806,858, for example, describes an inspection technique for magnetization that utilizes liquid crystal material to determine whether a sample has been appropriately magnetized. The use of a liquid crystal layer to change the magnetic flux resistance of a single magnetic path was described in Japanese Abstract No. 621 17757A2 (1985).

More recently, the magnetoelectric effects of liquid crystal materials in the form of magnetorestrictive and piezoelectric materials have been the subject of renewed research and development. Generally referred to as magnetoelectric (ME) materials, the research and development into various properties of these ME materials are described, for example, in Ryu et al., "Magnetoelectric Effect in Composites of Magnetorestrictive and Piezoelectric Materials," Journal of Electroceramics, Vol. 8, 107-119 (2002), Filippov et al., "Magnetoelectric Effects at Piezoresonance in Ferromagnetic-Ferroelectric Layered Composites," Abstract, American Physical Society Meeting (March 2003) and Chang et al., "Magnetoband of the Stacked Nanographite Ribbons," Abstract, American Physical Society Meeting (March 2003).

While many of the properties of ME materials are understood and there are numerous applications for the use of such liquid crystal materials, there is nothing which suggests how to make effective use of ME materials in the context of the design of permanent magnet motors and the like.

SUMMARY OF THE INVENTION

The present invention employs a coil-less magnetoelectric (ME) magnetic flux switching construct to repeatedly switch magnetic flux from at least one permanent magnet for the purposes of generating motive force and/or electrical energy. In one embodiment, a pair of permanent magnets are similarly oriented with each pole operably adjacent an associated first and second magnetic flux conductor. A first pair of coil-less ME magnetic flux switches are positioned between a corresponding first end of the first and second magnetic flux conductors and a third magnetic flux conductor. A second pair of coil-less ME magnetic flux switches are positioned between a corresponding second end of the first and second magnetic flux conductors and a fourth magnetic flux conductor. The first and second pairs of coil-less ME magnetic flux switches are repeatedly, alternately enabled to permit magnetic flux from the permanent magnets to cyclically flow through the third magnetic flux conductor and then the fourth magnetic flux conductor. Preferably, the coil-less ME magnetic flux switches are comprised of a laminate magnetoelectric (ME) material controlled by applying a voltage across the material to switch the magnetic conductivity of the ME material.

In one rotary motor embodiment of the present invention, the third and fourth magnetic flux conductors are different regions of a single rotor. The first and second magnetic flux conductors along with the permanent magnets serve as the stator. By continuous switching of the magnetic flux using

the pair of coil-less ME magnetic flux switches, rotational motive force is applied to the rotor and a rotary motor is created.

In another rotary motor embodiment of the present invention, the rotor is provided with the permanent magnets and the coil-less ME magnetic flux switches and the stator is the common element that provides the different regions for the third and fourth magnetic flux conductors. In one version of this embodiment, the rotor may be the rotating element of the motor. In another version of this embodiment, the stator may be the rotating element of the motor.

In one rotary motor/generator embodiment of the present invention, one or more pickup coils are wound around at least one of the magnetic flux conductors of the stator element of a rotary motor. Unlike the motor construct of U.S. Pat. Nos. 6,246,561 and 6,342,746, current is not applied to any of these coils. Instead, the coils are used as the pickup coils of an alternating current generator. In an alternate embodiment of this invention, a current may be applied to the coils to utilize these coils as control coils to enhance or supplement the magnetic flux switching effected by the coil-less ME magnetic flux switches as described by the present invention, or to provide additional operational benefits to the magnetic flux switching constructs as described in this invention and/or U.S. Pat. Nos. 6,246,561 and 6,342,746.

In one solid state generator embodiment of the present invention, a pickup coil is wound around at least one of the first and second magnetic flux conductors of a given solid state flux switching construct. In one version of this solid state generator embodiment, at least one of the first and second magnetic flux conductors having a pickup coils is shared by two or more solid state flux switching constructs. In another version of this solid state generator embodiment, a pickup coil is wound around at one of the third and fourth magnetic flux conductors of a given solid state flux switching construct and at least one of the third and fourth magnetic flux conductors are shared by two or more solid state flux switching constructs.

In another embodiment of a solid state generator in accordance with the present invention, a permanent magnet is at least partially coaxially surrounded by at least one coil-less ME magnetic flux switch with at least one coil positioned outside the coil-less magnetic flux switch. In a first version of this embodiment, the coil is wrapped coaxially with the permanent magnet and the coil-less magnetic flux switch. In a second version of this embodiment, the coil is positioned transverse to a longitudinal axis of the permanent magnet. In a third version of this embodiment, the coil is wrapped as one or more torroids positioned around the permanent magnet.

In another embodiment, at least one permanent magnet has each pole operably adjacent an associated first and second magnetic flux conductor. The first and second magnetic flux conductors each include a pair of selectively enabled permanent magnets with opposite pole orientations. Each permanent magnet in the first and second magnetic flux conductor is selectively enabled in this embodiment by a corresponding pair of coilless magnetic flux switches interposed between the poles of each of these magnets and the corresponding adjacent portions of the first and second magnetic flux conductors. In one version of this embodiment, the pair of magnets in the first and second magnetic flux conductors can be separated with a magnetic insulator material such as MU metal. In another embodiment, a third and fourth magnetic flux conductor can be added to the corresponding end of the first and second magnetic flux

conductors with an additional set of interposed coil-less magnetic flux switches arranged as described in the preferred embodiment.

In a linear motor/actuator embodiment in accordance with the present invention, the third and fourth magnetic flux conductors are effectively rails along which a shuttle is moved between carrying the permanent magnets, the first and second magnetic flux conductors and the coil-less ME magnetic switches.

In a preferred embodiment, the coil-less ME magnetic flux switches are implemented as a liquid crystal ME material that is electronically controllable. In an alternate embodiment, the ME material may be physically or optically controllable. Preferably, the ME material is processed onto a desired surface of the magnetic flux conductor or permanent magnet by thin film deposition, sputtering, or other thin film processing techniques. Alternatively, the ME material may be positioned physically interposed between the desired surfaces of the magnetic flux conductors or permanent magnets. In one embodiment, an index matching coating material may be interposed between the ME material and the desired surface of the magnetic flux conductors or permanent magnets to improve the magnetic flux characteristics of the completed construct. In another embodiment, a magnetic insulator material, such as MU metal can be used to house an entire magnetic flux switching construct to prevent external magnetic fields or may be used to magnetically isolate selected portions of a magnetic flux switching construct.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1 and 2 are schematic diagrams of a preferred embodiment of magnetic flux switching construct in accordance with the present invention.

FIG. 3 is a schematic diagram of one embodiment of a motor/generator in accordance with the present invention.

FIG. 4 is a schematic diagram of an alternate embodiment of a rotary motor in accordance with the present invention.

FIG. 5 is a schematic diagram of an alternative embodiment of a magnetic flux switching construct in accordance with the present invention.

FIGS. 6 and 7 are schematic diagrams of alternate embodiments of a motor/generator in accordance with the present invention.

FIGS. 8, 9 and 10 are schematic diagrams of alternative embodiments of a magnetic flux switching construct in accordance with the present invention.

FIG. 11 is a top plan view of a coaxial construction of a generator in accordance with the present invention.

FIG. 12 is a side view of the embodiment shown in FIG. 11.

FIG. 13 is a side view of an alternate embodiment of a coaxial construction of a generator in accordance with the present invention.

FIG. 14 is a side view of an embodiment of a coaxial construction of a generator in accordance with the present invention.

FIGS. 15 and 16 are schematic views of alternate embodiments of multiple flux switching constructs in accordance with one embodiment of the present invention.

FIG. 17 is a schematic diagram of an alternate embodiment of a linear motor/actuator in accordance with the present invention.

DETAILED DESCRIPTION OF THE DRAWINGS

Referring to FIGS. 1 and 2, a first embodiment of a magnetic flux switching construct 100 in accordance with

the present invention will be described. A pair of permanent magnets **102**, **104** are similarly oriented with each north pole (N) operably adjacent a first magnetic flux conductor **112** and each south pole (S) operably adjacent a second magnetic flux conductor **114**. Preferably, the permanent magnets **102**, **104** are high strength ceramic or rare-earth permanent magnets such as neodymium, although any material capable of being magnetized and retaining that magnetization for a period of time sufficient for the intended use of the construct **100** could be used. Preferably, the magnetic flux conductors **112**, **114** are low loss magnetic flux laminate materials, such as hyperco or an MD grade metal, although any iron, steel or ferrous alloy could be used provided that the magnetic flux loss of such material is within the design parameters of the strength of magnetic flux to be switched by the construct **100**.

A first pair of coil-less magnetoelectric (ME) magnetic flux switches **142**, **144** are sandwiched between a corresponding first end of the first and second magnetic flux conductors **112**, **114** and a third magnetic flux conductor **122**. A second pair of coil-less ME magnetic flux switches **152**, **154** are positioned between a corresponding second end of the first and second magnetic flux conductors **112**, **114** and a fourth magnetic flux conductor **124**. Preferably, each of the first and second pairs of coil-less ME magnetic flux switches **142**, **144**, **152**, **154** are repeatedly, alternately enabled by an electronic control circuit **150** (shown for convenience as connected to just one switch). Preferably, the coil-less ME magnetic flux switches **142**, **144**, **152**, **154** are comprised of a laminate magnetoelectric (ME) material such as the ME materials described in Ryu et al., "Magnetoelectric Effect in Composites of Magnetostrictive and Piezoelectric Materials," Journal of Electroceramics, Vol. 8, 107-119 (2002). Alternatively, the ME materials may be any ME or liquid crystal material.

As shown in FIG. 1, the switching of the first pair of coil-less ME magnetic flux switches **142** and **144** into an "on" position and the second pair of coil-less ME magnetic flux switches **152** and **154** into the "off" position permits magnetic flux as shown at **132**, **134** from the permanent magnets **102**, **104** to flow through the third magnetic flux conductor **122** and not the fourth magnetic flux conductor **124**. Switching of the first pair of coil-less ME magnetic flux switches **142** and **144** into an "off" position and the second pair of coil-less ME magnetic flux switches **152** and **154** into the "on" position then permits magnetic flux as shown at **136**, **138** from the permanent magnets **102**, **104** to flow through the fourth magnetic flux conductor **124** and not the third magnetic conductor **122**.

As this switching process is cyclically repeated under control of control circuit **150**, the switching of the magnetic flux between the positions at **132**, **134** and the positions at **136**, **138** is accomplished. As will be described, there are numerous applications for this switching construct **100**. In the case of the embodiment shown in FIGS. 1 and 2, a pair of pickup coils **162**, **164** are wound around the first and second magnetic flux conductors **112**, **114**, respectively. Electricity is generated at these pickup coils by virtue of the switching magnetic flux. It will be seen that an AC output signal is generated at the terminals of the pickup coils with a frequency that is dependent upon the speed at which the switching process is cycled. The frequency is limited by the switching speeds of the specifications of the particular coil-less ME magnetic flux switches utilized. In a preferred embodiment of a laminate coil-less ME magnetic flux switch, switching frequencies may be up to 100 GHz. It will be apparent that numerous rectification, power conditioning

and other signal processing techniques can be used to modify the output of the pickup coils **162**, **164**. In one embodiment, at least a portion of the output of the pickup coils **162**, **164** is used to power the control circuit **150**.

Referring now to FIG. 3, the use of the magnetic flux switching construct of the present invention in a rotary motor application will be described. In general, the arrangement of components in this embodiment is similar to the rotary motors as described in U.S. Pat. Nos. 6,246,561 and 6,342,746, except that no control coils are used to control switching of the magnetic flux. The rotary motor **200** includes components that are similar to those used in the magnetic flux switching construct **100** except that the third magnetic flux conductor **122** and fourth magnetic flux conductor **124** are different regions of a single rotor element **202**. Preferably, the rotor element **202** includes a number of notches **210** that are dimensioned to permit the selectively coupling of the magnetic flux through the enabled pair of switches **142**, **144** or **152**, **154** in a timed manner to generate an effective rotating force in one rotational direction. The first and second magnetic flux conductors **112**, **114** are curved and along with the permanent magnets **102**, **104** serve as the stator **204** of the rotary motor **200**. By continuous switching of the magnetic flux using the pair of coil-less ME magnetic flux switches **142**, **144** and **152**, **154**, rotational motive force is applied to the rotor **202**. It will be seen that a rotary motor **200** having any even number of poles could be constructed, such as a six pole motor or a twelve pole motor, for example. For a detailed understanding of the timing and construction of a control circuit that would enable the switches **142**, **144**, **152**, **154**, reference is made to U.S. Pat. Nos. 6,246,561 and 6,342,746.

In another embodiment of a rotary motor **220** as shown in FIG. 4, the rotor **222** is provided with the permanent magnets and the coil-less ME magnetic flux switches **142**, **144**, **152**, **154** and the stator **224** is the common element that provides the different regions for the third and fourth magnetic flux conductors **122**, **124**. In one version of this embodiment, the rotor **222** may be the rotating element of the motor **220**. In another version of this embodiment, the stator **224** may be the rotating element of the motor **220**. In one embodiment, the control circuit **150** can be carried by the rotor **222** and may be powered by a battery or by a shaft feed powered by pickup coils or an outside source.

In one rotary motor/generator embodiment as shown in FIG. 3, one or more pickup coils **162**, **164** are wound around at least one of the first and second magnetic flux conductors **112**, **114** of the stator **204** of rotary motor **200**.

In another embodiment as shown in FIGS. 5-7, at least one permanent magnet has each pole operably adjacent an associated first and second magnetic flux conductor. In one embodiment, the first and second magnetic flux conductors each include a pair of selectively enabled permanent magnets with opposite pole orientations. Each permanent magnet in the first and second magnetic flux conductor is selectively enabled in this embodiment by a corresponding pair of coil-less magnetic flux switches interposed between the poles of each of these magnets and the corresponding adjacent portions of the first and second magnetic flux conductors. In one version of this embodiment, the pair of magnets in the first and second magnetic flux conductors can be separated with a magnetic insulator material such as MU metal. In another embodiment, a third and fourth magnetic flux conductor can be added to the corresponding end of the first and second magnetic flux conductors with an additional set of interposed coil-less magnetic flux switches arranged as described in the preferred embodiment. This construct can

be used to create a rotary motor/generator as shown in FIGS. 6-7, with any number of pickup coils.

In another embodiment as shown in FIG. 8, a single permanent magnet is used to provide magnetic flux for the magnetic flux switching construct and multiple pick up coils are arranged on each of the first and second magnetic flux conductors.

In another embodiment as shown in FIG. 9, a pair of permanent magnets are used to selectively provide magnetic flux with a second set of coil-less ME magnetic flux switches interposed in between the poles of each of the permanent magnets and the first and second magnetic flux conductors. This second set of coil-less ME magnetic flux switches may be controlled by the control circuit for the first set of coil-less ME magnetic flux switches that selectively flux connect the third and fourth magnetic flux conductors or may be controlled by a separate control circuit. FIG. 10 is an alternate embodiment of the embodiment shown in FIG. 9 with a pair of paired and coil-less ME magnetic flux switched set of permanent magnets used to generate magnetic flux for the present invention.

In another embodiment of a solid state generator as shown in FIGS. 11-14, a permanent magnet is at least partially coaxially surrounded by at least one coil-less ME magnetic flux switch with at least one coil positioned outside the coil-less magnetic flux switch. In a first version of this embodiment as shown in FIGS. 11 and 12, the coil is wrapped coaxially with the permanent magnet and the coil-less magnetic flux switch. In a second version of this embodiment as shown in FIG. 13, the coil is positioned transverse to a longitudinal axis of the permanent magnet. In a third version of this embodiment as shown in FIG. 14, the coil is wrapped as one or more torroids positioned around the permanent magnet.

In a solid state generator embodiment of the present invention as shown in FIGS. 15, a pickup coil is wound around at least one of the first and second magnetic flux conductors of a given solid state flux switching construct. In this embodiment, at least one of the first and second magnetic flux conductors having a pickup coil is shared by two or more solid state flux switching constructs. In another version of this solid state generator embodiment as shown in FIG. 16, a pickup coil is wound around at one of the third and fourth magnetic flux conductors of a given solid state flux switching construct and at least one of the third and fourth magnetic flux conductors are shared by two or more solid state flux switching constructs.

In a linear motor/actuator embodiment in accordance with the present invention as shown in FIG. 17, the third and fourth magnetic flux conductors are effectively rails along which a shuttle is moved between carrying the permanent magnets, the first and second magnetic flux conductors and the coil-less ME magnetic switches. The rails may be tied together as part of a common superstructure. One or more sets of the magnetic flux switching construct may be incorporated into the shuttle portion of this embodiment.

It will be apparent that numerous combinations of the various embodiments of the present invention may be arranged in different combinations to take advantage of different aspects of the present invention.

The complete disclosures of the patents, patent applications and publications cited herein are incorporated by reference in their entirety as if each were individual incorporated. Various modifications and alterations to this invention will become apparent to those skilled in the art without departing from the scope or spirit of this invention.

I claim:

1. An apparatus for switching magnetic flux comprising:
 - a first permanent magnet having a north pole and a south pole;
 - a second permanent magnet having a north pole and a south pole;
 - a plurality of magnetic flux conductors operably connected to define a plurality of magnetic paths including a first magnetic path between the north pole and the south pole of the first permanent magnet, a second magnetic path between the north pole and the south pole of the second permanent magnet, a third magnetic path between the north pole of the first permanent magnet and the north pole of the second permanent magnet, and a fourth magnetic path between the south pole of the first permanent magnet and the south pole of the second permanent magnet;
 - at least a first coil-less magnetoelectric flux switch made of a composite material and operably positioned to switchably turn OFF and ON a flow of magnetic flux in the first magnetic path;
 - at least a second coil-less magnetoelectric flux switch made of a composite material and operably positioned in the second magnetic path to switchably turn ON and OFF a flow of magnetic flux in the second magnetic path;
 - a first pickup coil wound around the magnetic flux conductor of the third magnetic path; and
 - a control system operably connected to the first and second magnetoelectric flux switches to selectively switch the flow of magnetic flux from the first permanent magnet and the second permanent magnet through different ones of the plurality of magnetic paths by turning ON the flow of magnetic flux in at least one magnetic path and turning OFF the flow of magnetic flux in a different one of the plurality of magnetic paths such that a flow of current is generated in the first pickup coil.
2. The apparatus of claim 1, wherein the control system selectively controls at least one magnetic property of the first and second magnetoelectric flux switches by electronic control applied to the magnetoelectric flux switches.
3. The apparatus of claim 2, wherein the composite material includes a laminate that includes a piezoelectric material.
4. The apparatus of claim 3, further comprising a second pickup coil wound around the magnetic flux conductor of the fourth magnetic path such that a flow of current is generated in the second pickup coil by the selective switching of the flow of magnetic flux from the first permanent magnet and the second permanent magnet.
5. The apparatus of claim 3, wherein the laminate further includes a magnetostrictive material.
6. The apparatus of claim 1, further comprising a second pickup coil wound around the magnetic flux conductor of the fourth magnetic path such that a flow of current is generated in the second pickup coil by the selective switching of the flow of magnetic flux from the first permanent magnet and the second permanent magnet.
7. The apparatus of claim 1, wherein the composite material includes a laminate that includes a piezoelectric material.
8. The apparatus of claim 7, wherein the laminate further includes a magnetostrictive material.
9. A method for switching magnetic flux generated by a first and second permanent magnet, each having a north pole and a south pole, the method comprising:

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operably connecting a plurality of magnetic flux conductors to define a plurality of magnetic paths including a first magnetic path between the north pole and the south pole of the first permanent magnet, a second magnetic path between the north pole and the south pole of the second permanent magnet, a third magnetic path between the north pole of the first permanent magnet and the north pole of the second permanent magnet, and a fourth magnetic path between the south pole of the first permanent magnet and the south pole of the second permanent magnet;

operably positioning at least a first coil-less magnetoelectric flux switch made of a composite material to switchably turn OFF and ON a flow of magnetic flux in the first magnetic path;

operably positioning at least a second coil-less magnetoelectric flux switch made of a composite material to switchably turn ON and OFF a flow of magnetic flux in the second magnetic path;

providing a first pickup coil wound around the magnetic flux conductor of the third magnetic path;

providing a second pickup coil wound around the magnetic flux conductor of the fourth magnetic path;

controlling the first and second coil-less magnetoelectric flux switches to selectively switch the flow of magnetic flux from the first permanent magnet and the second permanent magnet through different ones of the plurality of magnetic paths by turning ON the flow of magnetic flux in at least one magnetic path and turning OFF the flow of magnetic flux in a different one of the plurality of magnetic paths such that a flow of current is generated in the first and second pickup coils.

10. The method of claim 9, wherein the controlling of the first and second coil-less magnetoelectric flux switches includes electronically controlling the first and second magnetoelectric flux switches.

11. The method of claim 10, wherein the first coil-less magnetoelectric flux switch includes a laminate that includes a piezoelectric material.

12. The method of claim 11, wherein the laminate further includes a magnetostrictive material.

13. The method of claim 9, wherein the operably positioning of the first coil-less magnetoelectric flux switch made of the composite material includes positioning a laminate that includes a piezoelectric material in the magnetic path.

14. The method of claim 13, wherein the laminate further includes a magnetostrictive material in the magnetic path.

15. A method for generating a flow of current in a first pickup coil associated with switching of magnetic flux generated by a first permanent magnet and a second permanent magnet, each having a north pole and a south pole, the method comprising:

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operably connecting a plurality of magnetic flux conductors to define a plurality of magnetic paths including a first magnetic path between the north pole and the south pole of the first permanent magnet, a second magnetic path between the north pole and the south pole of the second permanent magnet, a third magnetic path between the north pole of the first permanent magnet and the north pole of the second permanent magnet, and a fourth magnetic path between the south pole of the first permanent magnet and the south pole of the second permanent magnet;

operably positioning at least a first coil-less magnetoelectric flux switch made of a composite material to switchably turn OFF and ON a flow of magnetic flux in the first magnetic path;

operably positioning at least a second coil-less magnetoelectric flux switch made of a composite material to switchably turn ON and OFF a flow of magnetic flux in the second magnetic path;

providing the first pickup coil wound around the magnetic flux conductor of the third magnetic path; and

controlling the first and second coil-less magnetoelectric flux switches to selectively switch the flow of magnetic flux from the first permanent magnet and the second permanent magnet through different ones of the plurality of magnetic paths such that a flow of current is generated in the first pickup coil by alternately switching the flow of magnetic flux through the at least two magnetic flux conductors by turning ON the flow of magnetic flux in at least one magnetic path and turning OFF the flow of magnetic flux in a different one of the plurality of magnetic paths.

16. The method of claim 15, wherein the controlling of the first and second coil-less magnetoelectric flux switches includes electronically controlling the first and second magnetoelectric flux switches.

17. The method of claim 15, wherein the operably positioning of the first coil-less magnetoelectric flux switch made of the composite material includes positioning a laminate that includes a piezoelectric material in the magnetic path.

18. The method of claim 17, wherein the controlling of the first and second coil-less magnetoelectric flux switches is done electronically.

19. The method of claim 17, wherein the laminate further includes a magnetostrictive material.

20. The method of claim 19, wherein the controlling of the first and second coil-less magnetoelectric flux switches is done electronically.

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